2.6 OFF-BOARD NOISE ECM

Off-board ECM involves jamming devices carried by the target platform and deployed externally. For example, such a device can be launched from the platform (as with an expendable decoy), or towed behind it.

2.6.1 Functional Element Design Requirements

Section 2.5.1, On-Board Noise Functional Element Design Requirements, contains basic ECM requirements that apply to all of the *RADGUNS* noise ECM FEs. This section contains an additional design requirement necessary to implement the simulation of off-board noise ECM in *RADGUNS*.

Off-board noise jamming devices modeled will include expendables which will follow a ballistic trajectory, and towed jammers which will trail the target aircraft at a distance that increases linearly with time after jamming was initiated.

2.6.2 Functional Element Design Approach

This section describes the design elements that implement the off-board noise ECM design requirements. The design approach used to implement off-board noise ECM is the same as the approach for on-board noise ECM (FE 1.3.1.1), other than the manner in which the position of the jammer is calculated. Only the portions of the approach that are specific to off-board noise jamming are given here. Refer to Section 2.5.2 and the associated design elements for additional off-board noise ECM design information.

Design Element 6-1: Jammer Power

A nominal jammer power value for use in the jammer signal power Equation [2.5-3] is input by the user. In addition, amplitude modulation may be used to vary the jammer power output level. See Design Element 5-1 for more information.

Design Element 6-2: Effective Portion of Jammer Bandwidth

The effective portion of the jammer bandwidth is discussed in Design Element 5-2.

Design Element 6-3: Design Element 6-3: Jammer Position

For off-board ECM, the jammer position is offset from the target position by a distance that varies over time. Until the jammer becomes active, the jammer position is the same as that of the target. After the jammer becomes active, the position is computed depending on the type of off-board jammer being simulated.

If the jammer is an expendable device, a trajectory is computed beginning with an initial position and velocity identical to that of the launch aircraft at the start of jamming. A position update is done in two steps: the velocity components are updated first, followed by an update to the position coordinates. User deceleration inputs determine the velocity of the expendable from the last updated velocity, using:

$$v_x(new) = v_x \left[1 - \frac{d_h \Delta t}{\sqrt{v_x^2 + v_y^2}}\right] \qquad [2.6\text{-}1]$$

$$v_y(new) = v_y \left[1 - \frac{d_h \Delta t}{\sqrt{v_x^2 + v_y^2}}\right] \qquad [2.6\text{-}2]$$

$$v_z(new) = v_z - d_z \Delta t \qquad [2.6\text{-}3]$$

where:
- v_x(new)= expendable velocity component in the x-direction, updated (m/s)
- v_y(new)= expendable velocity component in the y-direction, updated (m/s)
- v_z(new)= expendable velocity component in the z-direction, updated (m/s)
- v_x, v_y, v_z= current expendable velocity components, in x,y,z directions (m/s)
- d_h = horizontal deceleration (m/s^2)
- d_z = vertical deceleration (m/s^2)
- Δt = time since last update (s)

If the current values of the velocity components are such that any of the updates will change sign, the new components are set to zero.

Once the velocity components of the expendable are updated, the position coordinates are updated using:

$$\begin{aligned} x(\text{new}) &= x(\text{old})\ v_x(\text{new})\ \Delta t \\ y(\text{new}) &= y(\text{old})\ v_y(\text{new})\ \Delta t \\ z(\text{new}) &= z(\text{old})\ v_z(\text{new})\ \Delta t \end{aligned} \qquad [2.6\text{-}4]$$

Equation [2.6-3] is a straightforward application of the equations of motion. However, because the magnitude of the deceleration in the horizontal plane is assumed to be independent of the particular velocity direction in the horizontal (x, y) plane, the x and y components of deceleration are dependent on the direction. If the direction of deceleration is the same as the direction of velocity, then the deceleration components can be computed by multiplying the horizontal deceleration by the ratios of the velocity x, y components to the magnitude of the velocity vector in the (x, y) plane:

$$d_x = d_h \frac{v_x}{\sqrt{v_x^2 + v_y^2}} \quad \text{and} \quad d_y = d_h \frac{v_y}{\sqrt{v_x^2 + v_y^2}}$$

If the above equation for d_x is substituted into:

$$v_x(\text{new}) = v_x - d_x \Delta t$$

the result is:

$$v_x(\text{new}) = v_x - d_h \Delta t \frac{v_x}{\sqrt{v_x^2 + v_y^2}}$$

If v_x is factored from both terms on the right side, this equation becomes identical to [2.6-1]. A similar process for y yields [2.6-2].

Note: The update method for the *x* and *y* velocity components of an expendable jammer appears to be implemented incorrectly in the *RADGUNS* v.2.0 code. The product of the deceleration and the time difference is multiplied by each of the velocity components without factoring the deceleration into *x* and *y* components. This error has been reported in MDR 96-01.

A towed jammer is located at the end of a cable attached to the target aircraft. It is assumed that the cable is let out at a constant rate, beginning at the same time that jamming is initiated. The length of the cable is zero if jamming has not yet started. After the jamming begins:

$$L = Max\{R_c\,(Tt_0),\, L_{max}\} \qquad [2.6\text{-}5]$$

where:

	L	=	length of the tow cable at time T (m)
	R_c	=	cable extension rate (m/s)
	T	=	current simulation time (s)
	t_0	=	time jamming was initiated (s)
	L_{max}	=	maximum cable length (m)

Once the cable length has been determined, the jammer position can be calculated using the target's velocity components. The tow cable is assumed to trail the target in a direction opposite from its velocity vector $\mathbf{V}_t$, so that:

$$l_x = -\frac{v_{xt}}{|\mathbf{V_t}|}L \quad \text{and} \quad x_j = x_t - \frac{v_{xt}}{|\mathbf{V_t}|}L$$

where:

	l_x	=	projection of tow cable on x-axis (m)
	v_{xt}	=	velocity along x-axis (m/s)
	$\lvert\mathbf{V}_t\rvert$	=	magnitude of target velocity vector = $\sqrt{v_{xt}^2 + v_{yt}^2 + v_{zt}^2}$ (m)
	x_t	=	*x* coordinate of target (m)
	x_j	=	*x* coordinate of jammer (m)

Similarly, equations for *y* and *z* can be derived, to give:

$$x_j = x_t - \frac{v_{xt}}{|\mathbf{V_t}|}L \quad y_j = y_t - \frac{v_{yt}}{|\mathbf{V_t}|}L \quad z_j = z_t - \frac{v_{zt}}{|\mathbf{V_t}|}L \qquad [2.6\text{-}6]$$

Design Element 6-4: Range to Jammer

The distance from the radar to the jammer is calculated with Equation [2.5-6] using the current jammer position coordinates relative to the radar, as discussed in Design Element 6-3.

Design Element 6-5: Design Element 6-5: Jamming Criteria

The criteria for beginning and ending active jamming are discussed in Design Element 5-4.

Design Element 6-6: Design Element 6-6: Estimated Crossover Range

A predicted crossover, or burn-through range is calculated at the time each jammer becomes active. The equation used to compute the estimated crossover range, Equation [2.5-8], is derived in Design Element 5-5; however, portions of that derivation apply only to a jamming source that is collocated with the target. The last few steps of the derivation are repeated here, for the more general case of a jammer not located on the target platform.

Repeating equation [2.5-11], jammer to target signal ratio is given by:

$$JS = \frac{4\pi P_J G_J G_{RJ} R_{RT}^4}{P_R G_{RT}^2 \sigma R_{RJ}^2} \left[\frac{B_R}{B_J}\right] \qquad [2.6\text{-}7]$$

where:

where:	JS	=	Jamming signal to target signal ratio (dimensionless)
	P_J	=	average jammer power at the antenna input (W)
	G_J	=	gain of jammer antenna, including losses (dimensionless)
	G_{RJ}	=	radar receiver gain in the direction of the jammer (dimensionless)
	R_{RT}	=	the range from the radar to the target (m)
	P_R	=	radar transmitter power (W)
	G_{RT}	=	radar antenna gain in the direction of the target (dimensionless)
	σ	=	target radar cross section (RCS) (m^2)
	R_{RJ}	=	range from jammer to radar (m)
	B_R	=	radar receiver noise bandwidth (Hz)
	B_J	=	jammer transmit bandwidth (Hz), with $B_J \geq B_R$

For a jammer that is not collocated with the target, Equation [2.6-7] cannot be simplified as in Equation [2.5-11]. Equation [2.6-7] can be written to show the dependence of certain variables on scenario time, where t_0 is the jamming initiation time.

$$JS = \frac{4\pi P_J G_J G_{RJ}(t_0) R_{RT}^4(t_0)}{P_R G_{RT}^2 \sigma(t_0) R_{RJ}^2(t_0)} \left[\frac{B_R}{B_J}\right] \qquad [2.6\text{-}8]$$

At time t_1, crossover occurs, and JS is assumed to be 1. Equation [2.6-7] becomes:

$$1 = \frac{4\pi P_J G_J G_{RJ}(t_1) R_{RT}^4(t_1)}{P_R G_{RT}^2 \sigma(t_1) R_{RJ}^2(t_1)} \left[\frac{B_R}{B_J}\right] \qquad [2.6\text{-}9]$$

Dividing [2.6-8] by [2.6-9] yields:

$$JS = \frac{G_{RJ}(t_0)\,R_{RT}^4(t_0)\sigma(t_1)\,R_{RJ}^2(t_1)}{G_{RJ}(t_1)\,R_{RT}^4(t_1)\sigma(t_0)R_{RJ}^2(t_0)} \qquad [2.6\text{-}10]$$

Solving for $R_{RT}(t_1)$ gives:

$$CR = R_{RT}(t_1) = R_{RT}(t_0)\sqrt{\frac{R_{RJ}(t_1)}{R_{RJ}(t_0)}}\sqrt[4]{\frac{1}{JS}}\sqrt[4]{\frac{G_{RJ}(t_0)\sigma(t_1)}{G_{RJ}(t_1)\sigma(t_0)}} \qquad [2.6\text{-}11]$$

The simplified Equation [2.5-8] is a reasonable estimate for the crossover range for a target protected by an off-board jammer only if the jamming source remains close to the target platform in range and angle and the target RCS, σ, does not vary significantly over time.

2.6.3 Functional Element Software Design

This section contains the software design necessary to implement the functional element requirement described in Section 2.6.1 and the design approach outlined in Section 2.6.2. The majority of the software employed to implement the Off-Board Noise ECM FE is identical to that of the On-Board Noise ECM FE. The design of that software is discussed in Section 2.5.3. This section focuses on the differences in the computation of the jammer location shown in Design Element 6-3. A logical flow chart of subroutine MOVJAM, as it applies to off-board jammers, is included together with a description of important operations represented by each block in the chart. A final subsection contains additional input and output data required to support the calculation of the off-board jammer position in subroutine MOVJAM. Section 2.5.3 contains input and output data for the FE as a whole and for each subroutine that implements the Off-Board Noise ECM FE.

Subroutine Design

The calling sequence of the Off-Board Noise ECM FE within the entire *RADGUNS* model structure is the same as for the On-Board Noise ECM FE. It is shown in Figure 2.5-1. Refer to Table 2.5-1 for a brief description of each of the subroutines.

<u>Logical Flow for Subroutine RADAR</u>. The functional flow diagram shown in Figure 2.5-2 displays the effect of the ECM FE on the logical flow of subroutine RADAR.

<u>Logical Flow for Off-Board Jammer Position Update MOVJAM</u>. Subroutine MOVJAM updates the position and velocity of each jamming source. Subroutine RADAR calls subroutine MOVJAM on a pulse-to-pulse basis to compute the current position and velocity of all active jammers. The current simulation time along with the target position, velocity, and acceleration are passed to subroutine MOVJAM. Figure 2.6-1 shows the logic flow of subroutine MOVJAM as it applies to off-board jammers. Portions of subroutine MOVJAM pertaining to other jammer classes are addressed in the corresponding ECM FEs (see On-Board and Standoff ECM FEs). The appropriate branch of MOVJAM is executed for each jammer.

RADGUNS simulates two types of off-board jammers—towed jammers which trail the target aircraft, and expendable jammers which are launched from the target aircraft. The type of jammer to be modeled is defined by the user-specified value for the jammer class. The two off-board jammer options are TOW and EXP. A towed jammer (TOW) is let out from the target aircraft at a constant velocity until the end of the tow cable is reached. An expendable jammer is released from the target aircraft and then exhibits user-input vertical and horizontal deceleration rates.

Blocks 1 through 11 are executed for each jammer.

Block 1. If the current jammer is not an off-board jammer, the jammer location is calculated by the appropriate method.

Blocks 2 and 3. If the user has requested a towed jammer, but the jammer has not become active yet, it is assumed that the jammer has not been released from the aircraft, and the length of the towing cable is set to zero (TOWLEN). When the jammer becomes active, the current time is saved as the time of release in array JXOFFS(II,3). Execution continues with block 7.

Block 4. Once the release time has been set, the length of cable released can be calculated as the product of the time after jammer release (T-JXOFFS(II,3)) and the rate at which the cable is let out (JXOFFS(II,2)).

Block 5. If the calculated cable length exceeds the total cable length specified by the user, it is set to the maximum (JXOFFS(II,1)) as in Equation [2.6-5].

Block 6. It is assumed that a towed jammer remains in line with the target velocity vector. Thus, the jammer location in any one direction can be calculated as the target position in the particular direction less the product of the length of cable released from the aircraft and a unit vector in the direction of travel. The position coordinates of the jammer are calculated as in [2.6-6].

Blocks 7 - 9. If the user has requested an expendable jammer, but the jammer has not yet become active, or if the jammer has just become active on this pulse, it is assumed that the jammer has not yet been released from the aircraft, and has a position and velocity equal to that of the target. When the jammer becomes active, the current time is saved as the time of release in array JXOFFS(II,3). Variable JXOFF(II,3) is initialized to zero in subroutine INPJAM.

Block 10. If an expendable jammer is active, the jammer velocity in the *x*- and *y* -directions is calculated as the previous jammer velocity in each direction less the product of the horizontal deceleration rate and the time since the last update. The *x*- and *y*-velocity components are limited to a minimum value of zero. The vertical velocity component is calculated as the last *z*-velocity less the product of the vertical deceleration rate and the time elapsed since the last update as in Equation [2.6-3]. The jammer's vertical descent rate is limited to a maximum value of 200 m/s.

Equations [2.6-1] and [2.6-2] give the method recommended in MDR 96-01 for computing the updated horizontal velocity components in terms of the horizontal deceleration constant.

Block 11. The jammer location in any direction is then calculated as the last known location in the direction of interest plus the amount the jammer has moved since the last update (the product of the jammer velocity and the elapsed time), using Equation [2.6-4]. The jammer's altitude is not permitted to fall below ground level. (All coordinates are referenced to the antenna location, so that ground level is equal to the height of the antenna in the negative *z*-direction.)

Block 12. When position information has been updated for all jammers, control is returned to subroutine RADAR.

Logical Flow for Subroutine JAMMER. Subroutine JAMMER is documented in the On-Board Noise ECM FE in Section 2.5.3.

Logical Flow for Subroutine NOISE. Subroutine NOISE is discussed in the On-Board Noise ECM FE in Section 2.5.3.

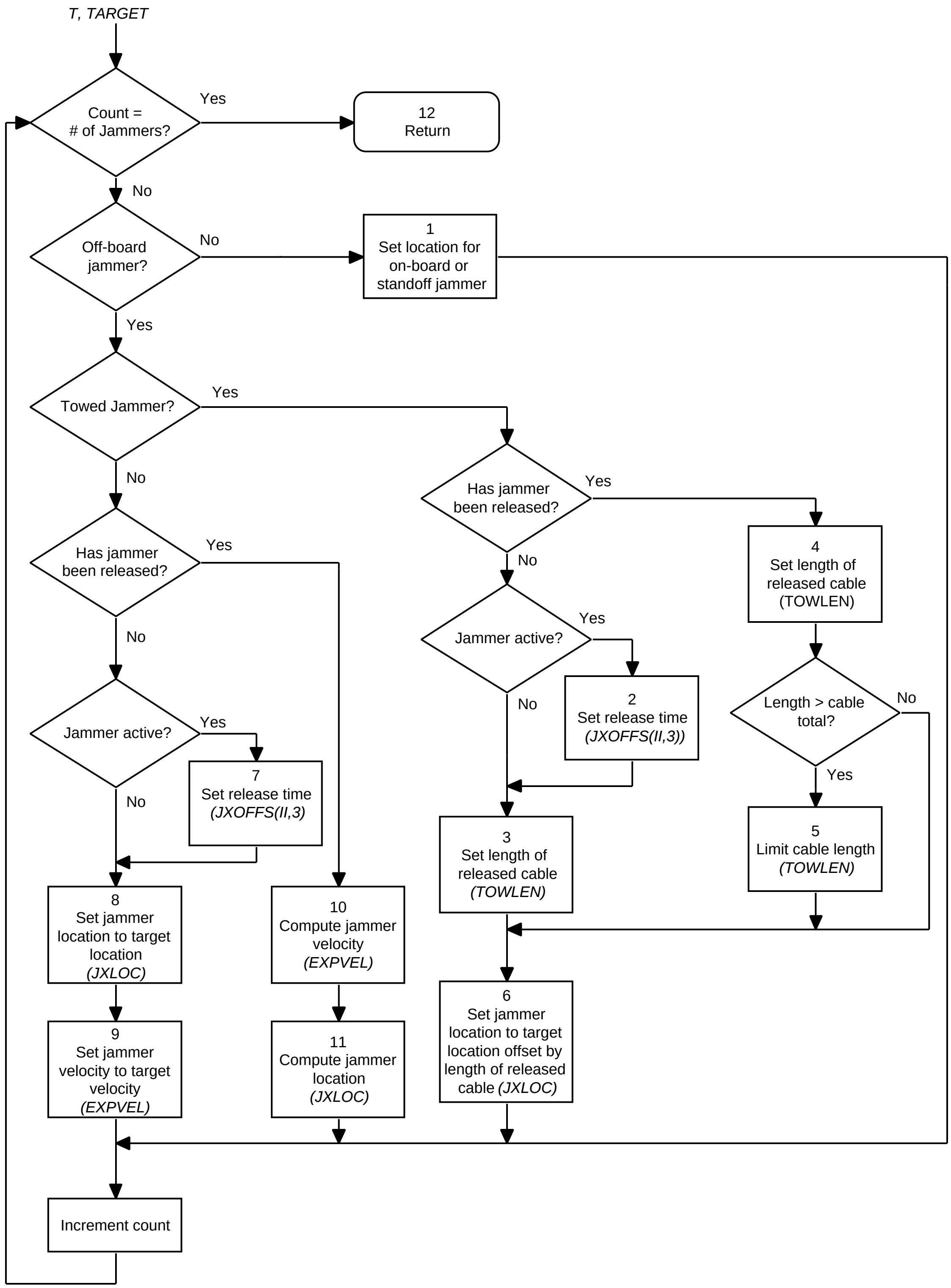

FIGURE 2.6-1. Subroutine MOVJAM Flow Chart, Off-Board ECM.

Functional Element Inputs and Outputs

All input and output parameters listed for the On-Board Noise ECM FE in Section 2.5.3 apply to the Off-Board Noise FE as well. Some additional parameters are employed to implement Off-Board Noise. This section identifies those additional input and output parameters specific to the Off-Board Noise ECM FE. There are no additions to the overall outputs shown in Table 2.5-2, subroutine JAMMER (Table 2.5-5), or subroutine NOISE (Table 2.5-6). There are some additions to the user inputs and to the subroutine MOVJAM parameters. A single user-input specific to off-board jamming is shown in Table 2.6-1, and the additional MOVJAM parameters are given in Table 2.6-2.

TABLE 2.6-1. Additional User Input for Off-Board ECM.

Variable Name	User Options	Description
JXOFFS	For TOW jammer class: JXOFFS(x,1) is any number in m; JXOFFS(x,2) is in m/s. For EXP class, both numbers are in m/s^2	For TOW jammer class: JXOFFS(x,1) is the tow cable length; JXOFFS(x,2) is the cable extension rate. For EXP jammer class: JXOFFS(x,1) is the horizontal deceleration rate; JXOFFS(x,2) is the vertical deceleration rate

TABLE 2.6-2. Subroutine MOVJAM Inputs and Outputs--Specific Parameters for Off-Board ECM.

SUBROUTINE: MOVJAM					
Inputs			**Outputs**		
Name	**Type**	**Description**	**Name**	**Type**	**Description**
T	Argument	Simulation time (s)			
JAMMED	COMMON	True when jammer active			
JXOFFS	COMMON	For towed jammer: length of tow cable (m) and cable extension rate (m/s). For expendable: horizontal and vertical deceleration rates			
HANT	COMMON	Height of radar antenna (m)			

2.6.4 Assumptions and Limitations

The assumptions and limitations given for the On-Board Noise ECM FE in Section 2.5.4 apply to all noise ECM FEs. Some additional assumptions and limitations specific to off-board ECM are listed below:

Jamming begins at deployment of the off-board towed or expendable jammer—not before or after.

A towed jammer maintains a constant angular orientation relative to the target as determined by the target’s instantaneous velocity, regardless of target maneuvers.